Research and Development Laboratories
of the
Portland Cement Association

RESEARCH DEPARTMENT

BULLETIN 82

Curing Requirements for Scale Resistance of Concrete

By

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JUNE, 1957

CHICAGO

Authorized Reprint from
HIGHWAY RESEARCH BOARD BULLETIN NO. 150
JANUARY, 1956

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The record of field performance of air-entrained concrete pavement with regard to surface scaling resulting from the use of de-icers is excellent. Approximately 15 years of field experience, together with extensive laboratory tests, have shown that the use of entrained air has solved an important pavement problem which was becoming more serious with the increasing use of chemicals for ice control.

The problem of the earliest age at which de-icers, such as calcium chloride, may safely be used on new air-entrained concrete pavements is of concern to highway engineers. This concern stems from previous practical experience with non-air-entrained concrete pavements. Shortly after the introduction of the use of de-icers, field surveys indicated that older non-air-entrained pavements resisted surface scaling better than relatively new non-air-entrained pavements. This led to the establishment of minimum ages at which de-icers might safely be used; however, the various highway departments were far from agreement on these age requirements. A recent survey of highway department practices, conducted by Committee B-7 of the Highway Research Board, indicates that these minimum ages ranged from a few months up to 5 and 10 years. Despite the excellent performance record of air-entrained concrete pavements, many states are applying the same age requirements to both types of concrete pavement.

Only a limited amount of information is available bearing directly on this problem (1). This study was undertaken, therefore, to provide additional information which might interest those concerned with the use of de-icers on new air-entrained concrete pavements.

● THE study consisted of laboratory surface scaling and strength tests of both non-air-entrained and air-entrained concretes. Types I, II, and III portland cements were used in preparing these concretes having essentially identical cement contents and slumps. Concretes with Type I and II cements were made both with and without calcium chloride added as an accelerator. Air entrainment was accomplished by adding an agent at the mixer.

The concretes were fabricated at one temperature level (40 deg F) to simulate cold weather construction. Specimens were cured at three different temperature levels (73 deg F, 40 deg F, and 25 deg F) for different periods of time before making strength determinations and testing for scale resistance. Curing periods prior to testing ranged from one day to 60 days, the selected intervals depending upon type of cement, presence or absence of an accelerator, and temperature of curing.

Materials

The cements used in these tests, all meeting applicable ASTM requirements, were obtained from commercial sources. The Type I cement was a blend prepared from equal parts of four different brands, the Type II was an individual brand, and the Type III cement was a blend of equal parts of two different brands. Tables 1, 2, 3, and 4 show the chemical compositions, calculated potential compound compositions, and the results of various physical tests of the cements and mortars made.

The fine aggregate was a predominantly dolomitic natural sand from Elgin, Illinois. The coarse aggregate, a highly siliceous crushed gravel from Eau Claire, Wisconsin, was selected as representative of sound, durable coarse aggregates commonly used in concrete pavement construction. Grading, specific gravity, absorption, and thermal coefficient of linear expansion are shown in Table 5.

TABLE 1

CHEMICAL COMPOSITION OF CEMENTS

Chemical analyses of cements made in accordance with ASTM method of test current in May, 1954. Sodium oxide and potassium oxide by flame photometry, ASTM C228-49T.

Cement		Major Components - %							Minor Components - %			Alkalies		
Lot No.	ASTM Type	SiO_2	Al_2O_3	Fe_2O_3	Total CaO	MgO	SO_3	Ign Loss	Mn_2O_3	Free CaO	Insol Res	Na_2O	K_2O	Tot. as Na_2O
18868	I	21.44	5.94	2.67	63.10	2.62	2.05	1.07	0.26	0.83	0.18	0.22	0.66	0.65
18914	II	21.26	5.08	3.72	61.61	3.77	1.70	1.61	0.07	0.86	0.18	0.26	0.75	0.75
18893	III	19.77	5.88	2.61	64.77	1.76	2.83	1.59	0.19	1.55	0.13	0.16	0.46	0.46

TABLE 2

POTENTIAL COMPOUND COMPOSITION OF CEMENTS

Corrected for free CaO

Cement		Calculated Compount Composition - %					
Lot No.	ASTM Type	C_3S	C_2S	C_3A	C_4AF	$CaSO_4$	Free CaO
18868	I	40.9	30.6	11.2	8.1	3.49	0.83
18914	II	41.4	29.7	7.2	11.3	2.89	0.86
18893	III	55.8	14.6	11.1	7.9	4.81	1.55

Aggregates were air-dried and screened into various size fractions — six sizes for the fine aggregate and three for the coarse aggregate. When batching, the sizes were recombined to yield the gradings shown in Table 5. Aggregates were weighed in the air-dried condition (moisture content known) and, 18 to 20 hours prior to use, inundated with a known amount of water. Prior to mixing, excess water was drawn off and weighed to permit calculating the net water-cement ratios.

Neutralized Vinsol resin in solution was added at the mixer when preparing the air-entrained concretes. Commercial flake calcium chloride was used both as the de-icer and the accelerator.

TABLE 3

MISCELLANEOUS PHYSICAL TESTS OF CEMENTS

Tests made in accordance with ASTM methods of test current in May, 1954. Each value is the average of two or more determinations.

Cement		Fineness					Time of Setting				
Lot No.	ASTM Type	Spec Surface sq cm per g		Passing 325 Mesh %	Specific Gravity	Normal Consistency %		Gilmore		Auto-clave Exp %	Air Content % 1-4 Mortar
		Wagner	Blaine				Vicat h. m.	Initial h. m.	Final h. m.		
18868	I	1630	3230	89.0	3.160	24.5	3:35	4:00	5:35	0.11	9.2
18914	II	1710	3275	90.0	3.180	23.0	4:20	5:25	7:10	0.13	9.3
18893	III	2520	5120	98.4	3.114	29.0	1:30	2:00	4:20	0.11	5.0

TABLE 4

STRENGTH TESTS OF MORTARS

Briquets: ASTM C190-49. Cubes: ASTM C109-52.
Each value is the average of three specimens, each made on a different day.

Cement		Tensile Strength, 1-3 Std Sand Mortar Briquets - psi				Compressive Strength, 2-in. Plastic Mortar Cubes - psi			
Lot No.	ASTM Type	1d	3d	7d	28d	1d	3d	7d	28d
18868	I	185	325	415	485	810	1850	3080	4460
18914	II	150	240	355	450	600	1420	2230	4000
18893	III	355	425	520	545	2110	3720	5200	6400

TABLE 5

DATA ON AGGREGATES

Elgin, Illinois, Sand									
Grading - % Retained On Sieve No. Indicated						Fineness Modulus	Bulk Specific Gravity S. S. D. [a]	24-Hr Absorption % by Wt	Mean Linear Thermal Coeff of Expansion [b]
4	8	16	30	50	100				
0	18	33	57	87	95	2.90	2.645	2.25	5.73×10^{-6}

Eau Claire, Wisconsin, Gravel						
Grading - % Retained On Sieve Size Indicated				Bulk Specific Gravity S. S. D. [a]	24-Hr Absorption % by Wt	Mean Linear Thermal Coeff of Expansion [b]
1-in.	¾-in.	⅜-in.	No. 4			
0	25	70	100	2.693	1.33	5.94×10^{-6}

[a] Saturated - surface dry.
[b] Dilatometer method.

Concrete Mix Data

The concretes were designed to have a cement content of 6 sacks per cu yd and a slump of 2½ to 3½ in. at 40 deg F. The maximum size of aggregate was 1 in. For the air-entrained concretes, the air content was maintained in the range of 5 ± ½ percent the optimum amount for these concretes (2). Where calcium chloride was used as an accelerator, it was used in the amount of 2 percent by weight of the cement and dissolved in a portion of the mixing water immediately before mixing. Table 6 shows the pertinent data for the concrete mixes used in this investigation.

Fabrication of Specimens

All materials were at a temperature of 40 deg F for 24 hours prior to mixing concretes. Mixing and fabricating operations were conducted in a laboratory maintained at 40 deg F, simulating temperature conditions likely to prevail during late fall paving.

Eight batches were prepared for each type of concrete. Batches were mixed for 2½ minutes in an open-tub mixer of 1¾-cu-ft capacity. A slump test and an air content determination by the pressure method were made on 4 of the 8 like batches. Each batch contained sufficient concrete for 4 scale test specimens and four 6- by 12-in. cylinders, making a total of 32 slabs and 32 cylinders per type of concrete.

The scale test specimens were slabs 3 in. in depth and 6 by 15 in. in area. These slabs were cast in watertight steel molds, the molds were filled in two layers of equal depth, and each layer was rodded 50 times with a ⅝-in. diameter bullet-nose tamper. Immediately after casting, the surface was given a final finish with a wood float. Approximately three hours after casting, the slabs were equipped with a 1:2 air-entrained mortar dike around the edges of the finished surface.

TABLE 6

CONCRETE MIX DATA

Ref No.	Cement Lot No.	Cement ASTM Type	Net W/C gal per sack	Slump in.	Cement Content sacks per cu yd	Air Content % (Pressure)
No $CaCl_2$ - Non-Air-Entrained						
1	18868	I	4.83	3.3	6.00	1.60
14	18914	II	4.63	2.8	6.02	1.70
3	18893	III	5.62	3.2	5.96	1.60
2% $CaCl_2$ - Non-Air-Entrained						
4	18868	I	4.79	2.6	5.96	1.90
15	18914	II	4.56	2.5	5.93	1.85
No $CaCl_2$ - Air-Entrained [a]						
7	18868	I	4.45	2.9	5.98	4.70
16	18914	II	4.37	2.8	5.96	5.30
9	18893	III	5.34	3.7	5.98	5.10
2% $CaCl_2$ - Air-Entrained [a]						
10	18868	I	4.32	2.5	5.96	4.80
17	18914	II	4.25	2.6	5.95	4.90

[a] Neutralized Vinsol resin in solution added at mixer.

TABLE 7

RESULTS OF SURFACE SCALING AND STRENGTH TESTS - TYPE I CEMENT

Type I Cement - Lot 18868. No $CaCl_2$.
Cement content of all concretes - 6 sacks per cu yd.
Neutralized Vinsol resin added at mixer for air-entrained concrete.
All specimens cured continuously moist for times indicated.
Net W/C: Non-A/E concrete - 4. 8 gal per sack. A/E concrete - 4. 5 gal. per sack.
Air content (pressure): Non-A/E - 1. 60%. A/E - 4. 70%

Days of Curing	Curing Temp F	Compressive Strength psi 6- x 12-in. Cyl	Scale Ratings at Indicated Number of Cycles									
			5	10	15	25	50	75	100	150	200	250
Non-Air-Entrained												
1	73	960	2	3	4+	(16)[a]						
3	73	2700	1-	2+	(15)							
28	73	6270	0	0	0+	3	(50)					
2	40	330	2	3	(15)							
4	40	1120	3+	4+	(13)							
6	40	1940	1+	3+	4+	(16)						
8	40	2960	1	3+	(15)							
12	40	4020	1	3	4+	(17)						
19	40	4880	1+	3	4+	(19)						
30	40	5540	1	4-	5-	(16)						
60	40	6410	0+	3+	4+	(23)						
9	25	440	0+	2	(15)							
18	25	560	0+	1	2	(16)						
28	25	560	0+	(10)								
40	25	520	1-	1+	3	(17)						
60	25	680	0+	1+	(15)							
Air-Entrained												
1	73	1050	1+	2	2	2+	3+	4-	(95)			
3	73	2720	0	0	0	0+	1-	1	1+	2-	2-	2-
28	73	5500	0	0	0	0+	0+	0+	0+	0+	0+	0+
2	40	420	3-	3+	4-	4+	(35)					
4	40	1060	2-	2	3+	4-	(40)					
6	40	1780	0+	0+	1-	1-	3-	3	3+	5-	5-	5-
8	40	2730	0	0+	0+	1-	1+	2	2+	4+	5-	5-
12	40	3460	0	0+	0+	1-	1+	2-	2-	2+	3+	4-
19	40	4360	0	0	0	0+	0+	0+	0+	1-	1+	2
30	40	4900	0	0	0	0+	0+	0+	0+	1-	1	1+
60	40	5680	0+	0+	0+	0+	0+	0+	0+	0+	1-	1-
9	25	540	0+	1-	2+	3+	(31)					
18	25	720	0+	1-	1	(22)						
28	25	900	0	0	0+	0+	1-	1	1+	(106)		
40	25	1030	0	1-	1-	1-	1-	1-	1	3	3	(220)
60	25	1010	0+	1-	1-	1-	1	1+	1+	2	(167)	

[a] ( ) - Number of cycles at which test was discontinued at a rating of 5.

TABLE 8

RESULTS OF SURFACE SCALING AND STRENGTH TESTS - TYPE I CEMENT

Type I Cement - Lot 18868 plus 2% $CaCl_2$, by weight of cement.
Cement content of all concretes - 6 sacks per cu yd.
Neutralized Vinsol resin added at mixer for air-entrained concrete.
All specimens cured continuously moist for times indicated.
Net W/C: Non-A/E concrete - 4.8 gal. per sack. A/E concrete - 4.3 gal. per sack.
Air content (pressure): Non-A/E - 1.90%. A/E - 4.80%.

Days of Curing	Curing Temp F	Compressive Strength psi 6- x 12-in. Cyl	Scale Ratings at Indicated Number of Cycles 5	10	15	25	50	75	100	150	200	250
			Non-Air-Entrained									
1	73	2260	3	4+	(11)[a]							
3	73	3940	0	0+	2	5-	(27)					
28	73	6460	0	0	0+	1	3-	(60)				
1	40	350	(5)									
2	40	1290	5-	(6)								
3	40	2340	2+	(9)								
4	40	2940	2+	4+	(13)							
7	40	4120	2-	3+	4+	(17)						
12	40	4970	1-	2	4	(21)						
30	40	5820	1-	2-	3-	(22)						
60	40	6560	0	0	0	0+	2	(55)				
2	25	640	4+	(6)								
5	25	1670	3-	4+	(12)							
10	25	2840	2-	3	5-	(16)						
30	25	3960	1-	1-	2-	2+	(36)					
60	25	3960	1+	2-	3-	3+	(36)					
			Air-Entrained									
1	73	2020	0+	1	1+	2-	3+	4-	4	4+	4+	5-
3	73	3450	0	0	0	0+	1-	1-	1+	2	2+	2+
28	73	5330	0	0	0	0+	0+	0+	0+	0+	0+	0+
1	40	340	(3)									
2	40	1340	3+	4+	4+	(19)						
3	40	2000	2-	3	3+	4-	(34)					
4	40	2540	0+	1-	1+	2-	2+	3-	3	3+	4-	4
7	40	3670	0	0	0	0	0+	0+	0+	0+	0+	1-
12	40	4530	0	0	0	0	0+	0+	0+	1-	(190)	
30	40	5170	0	0	0	0	0	0	0+	0+	0+	0+
60	40	5580	0	0	0	0	0	0	0	0+	0+	0+
2	25	340	2+	3+	4+	(19)						
5	25	980	2	3+	4+	(25)						
10	25	1480	1-	3+	4-	4+	(28)					
30	25	2270	0+	1	1	1	1	1	1	1	1	1
60	25	2520	0	0	0	0	0+	0+	0+	0+	0+	0+

[a]( ) - Number of cycles at which test was discontinued at a rating of 5.

TABLE 9

RESULTS OF SURFACE SCALING AND STRENGTH TESTS - TYPE II CEMENT

Type II Cement - Lot 18914. No $CaCl_2$.
Cement content of all concretes - 6 sacks per cu yd.
Nautralized Vinsol resin added at mixer for air-entrained concrete.
All specimens cured continuously moist for times indicated.
Net W/C: Non-A/E concrete -4. 6 gal. per sack. A/E concrete - 4. 4 gal. per sack.
Air content (pressure): Non-A/E - 1. 70%. A/E - 5. 30%.

Days of Curing	Curing Temp F	Compressive Strength psi 6- x 12-in. Cyl	Scale Ratings at Indicated Number of Cycles									
			5	10	15	25	50	75	100	150	200	250
			Non-Air-Entrained									
1	73	780	0+	3	(14)[a]							
7	73	3860	0+	1	2-	(22)						
28	73	6300	0+	1-	1+	2	3-	3+	(83)			
3	40	880	1-	3	(15)							
7	40	2560	0+	2-	2+	(20)						
12	40	3660	0+	0+	2+	(22)						
20	40	4780	0+	0+	2+	(25)						
30	40	5220	0+	0+	1-	2	(39)					
40	40	5990	0+	0+	1-	2	(38)					
50	40	6060	0+	0+	1-	1-	3					
60	40	6060	0+	0+	1-	2+	(50)					
8	25	560	0+	1+	(15)							
20	25	900	0+	1-	1+	(25)						
35	25	1180	0+	1-	1	2-	(29)					
45	25	1480	0+	1-	1	2-	(32)					
60	25	1490	0+	1-	1	1+	(50)					
			Air-Entrained									
1	73	650	0+	1	1+	2+	3	3	3+	3+	3+	3+
7	73	3250	0	0	0	0+	0+	0+	0+	0+	0+	0+
28	73	5520	0	0+	0+	0+	0+	0+	1-	1-	1-	1-
3	40	880	1-	3	4	4+	(42)					
7	40	2280	0	0+	0+	0+	1-	1-	1	1	1+	1+
12	40	3420	0	0	0+	0+	0+	0+	0+	1-	1-	1-
20	40	4280	0	0	0+	0+	0+	0+	0+	1-	1-	1-
30	40	4360	0	0	0+	0+	0+	0+	0+	1-	1-	1-
40	40	5010	0+	0+	0+	0+	0+	1-	1-	1	1	1
50	40	5360	0+	0+	0+	0+	0+	1-	1-	1-	1-	1
60	40	5120	0+	0+	0+	0+	1-	1	1	1	1	1
8	25	500	0	0+	0+	1-	1	1+	2-	2-	2	(190)
20	25	750	0+	0+	0+	1-	1-	1	1	1+	1+	1+
35	25	880	0	0+	1-	1-	1-	1-	1-	1-	1-	1-
45	25	1070	0	0+	0+	1-	1-	1-	1-	1-	1-	1-
60	25	1240	0+	0+	1-	1-	1-	1-	1-	1-	1-	1-

[a]( ) - Number of cycles at which test was discontinued at a rating of 5.

TABLE 10

RESULTS OF SURFACE SCALING AND STRENGTH TESTS - TYPE II CEMENT

Type II Cement - Lot 18914 plus 2% $CaCl_2$, by weight of cement.
Cement content of all concretes - 6 sacks per cu yd.
Neutralized Vinsol resin added at mixer for air-entrained concrete.
All specimens cured continuously moist for times indicated.
Net W/C: Non-A/E concrete - 4.6 gal. per sack. A/E concrete - 4.3 gal. per sack.
Air content (pressure): Non-A/E - 1.85%. A/E - 4.90%.

Days of Curing	Curing Temp F	Compressive Strength psi 6- x 12-in. Cyl	Scale Ratings at Indicated Number of Cycles									
			5	10	15	25	50	75	100	150	200	250
			Non-Air-Entrained									
1	73	1640	2+	(10)[a]								
7	73	4590	0	0	0+	1-	(36)					
28	73	6180	0	0+	0+	1-	2-	(69)				
1	40	260	3+	(7)								
2	40	930	3+	(9)								
5	40	2820	3+	(10)								
7	40	3680	1-	2+	3	(21)						
12	40	4620	0	0	0+	1-	(47)					
20	40	5630	0	0	0+	1-	(42)					
30	40	5980	0	0	0	0+	(45)					
60	40	6950	0	0	0	0+	(32)					
3	25	530	4-	(8)								
8	25	1890	3	4+	(12)							
16	25	3000	1-	2-	4-	4+	(32)					
32	25	4200	0	0+	1-	2+	3+	(70)				
60	25	4880	0	0+	0+	1-	3-	(60)				
			Air-Entrained									
1	73	1540	2+	4-	(13)							
7	73	4480	0	0	0	0+	0+	0+	0+	0+	1-	1
28	73	5720	0	0	0	0	0+	0+	0+	0+	0+	0+
1	40	250	4	(10)								
2	40	1000	4	(10)								
5	40	2820	0+	1+	2-	2+	3-	3+	3+	4-	4+	4+
7	40	3300	0	0+	1-	1-	1-	1-	1-	1-	1-	1-
12	40	4180	0	0	0	0	0	0+	0+	0+	0+	0+
20	40	4800	0	0	0	0	0	0	0	0	0	0+
30	40	5140	0	0	0	0	0	0	0	0	0	0
60	40	6020	0	0	0	0	0	0	0	0	0	0
3	25	530	3	(10)								
8	25	1500	2-	3+	4	4+	(34)					
16	25	2580	0	0+	1	1+	2+	2+	2+	2+	2+	3-
32	25	3340	0	0+	0+	0+	0+	0+	0+	0+	0+	0+
60	25	4200	0+	0+	0+	0+	0+	0+	0+	0+	0+	0+

[a] ( ) - Number of cycles at which test was discontinued at a rating of 5.

TABLE 11

RESULTS OF SURFACE SCALING AND STRENGTH TESTS - TYPE III CEMENT

Type III Cement - Lot 18893. No $CaCl_2$.
Cement content of all concretes - 6 sacks per cu yd.
Neutralized Vinsol resin added at mixer for air-entrained concrete.
All specimens cured continuously moist for times indicated.
Net W/C: Non-A/E concrete - 5.6 gal. per sack. A/E concrete - 5.3 gal. per sack.
Air content (pressure): Non-A/E - 1.60%. A/E - 5.10%.

Days of Curing	Curing Temp F	Compressive Strength psi 6- x 12-in. Cyl	Scale Ratings at Indicated Number of Cycles 5	10	15	25	50	75	100	150	200	250
			Non-Air-Entrained									
1	73	1600	2	2+	(13)[a]							
3	73	3560	0+	2+	4+	(18)						
28	73	5550	0	0+	2-	3-	(50)					
1	40	160	2	(10)								
3	40	1480	1	(10)								
5	40	2920	0	4	(15)							
7	40	4280	1-	3+	(14)							
9	40	4970	0+	1+	4	(19)						
12	40	5410	0	1+	3+	(23)						
30	40	6370	0	0+	1	3-	(40)					
60	40	6960	0	0	0+	2	(50)					
6	25	600	1-	2+	(15)							
13	25	1020	0	1+	3+	(19)						
21	25	770	0	0+	1+	(25)						
32	25	720	0	0	0+	(25)						
60	25	720	0	0	0+	1-	(31)					
			Air-Entrained									
1	73	1400	1-	2-	3-	4+	5-	(75)				
3	73	3020	0	0	0	0+	0+	1-	1+	3	3+	4-
28	73	4730	0	0	0	0	0+	0+	0+	0+	1-	1-
1	40	100	1+	3+	4+	(20)						
3	40	1350	1	2+	3+	4	(40)					
5	40	2660	0	0	0	0+	0+	1-	1+	2-	3	4-
7	40	3760	0	0	0	0+	0+	0+	1-	1+	2+	3+
9	40	4160	0	0	0	0	0	0	0+	0+	1-	1-
12	40	4920	0	0	0	0	0	0	0+	0+	1-	1-
30	40	6200	0	0	0	0	0	0	0+	0+	0+	0+
60	40	6310	0	0	0	0	0	0	0	0+	1-	1-
6	25	740	0+	2+	3+	4	(30)					
13	25	1830	0	0	0+	0+	1-	2	3	5-	5	(175)
21	25	2820	0	0	0	0	0+	1-	1+	2	2+	3
32	25	3440	0	0	0	0	0	0+	0+	0+	0+	0+
60	25	3260	0	0	0	0	0	0+	0+	0+	0+	0+

[a]( ) - Number of cycles at which test was discontinued at a rating of 5.

The 6- by 12-in. cylinders were cast in watertight steel molds, the molds were filled in three layers of equal depth, and each layer was rodded 25 times with a ⅝-in. diameter tamping rod.

Curing Conditions

Immediately after casting, six companion slabs and cylinders for each type of concrete were removed to a room maintained at 73 deg F; ten companion slabs and cylinders, to a room maintained at 25 deg F; and the remaining 16 companion slabs and cylinders remained in the casting room at 40 deg F. At the same time, specimens were covered with two thicknesses of damp burlap (not in contact with surface) and a tarpaulin. The molds were stripped the following day and moist curing continued in the 73 deg F and 40 deg F rooms. In the 25 deg F room, specimens were covered with two thicknesses of damp burlap which froze and prevented the specimens from drying out.

For each storage temperature, two companion slabs and cylinders were removed for scale and strength tests at different ages: three ages for the 73 deg F specimens, eight ages for the 40 deg F specimens, and five ages for the 25 deg F specimens. These curing periods varied with cement type, temperature of curing, and the presence or absence of an accelerator. Tables 7-11, presenting the strength and scale resistance data, indicate the specific lengths of curing before strength tests were made or the scale resistance cycles started.

Test Methods

Concrete cylinders were tested for compressive strength in accordance with current ASTM standards. A proprietary sulfur-containing capping compound was used to cap the top end of the cylinder. The cylinders stored at 25 deg F were thawed in the 73 deg F moist room for one hour prior to testing. The temperature at the center of the cylinder was about 45 deg F at the end of the thaw period.

The slabs were tested for resistance to surface scaling by alternately freezing a layer of water on the top surface and thawing the ice while a de-icer was distributed over the surface of the ice. The thaw period was limited to the amount of time required to raise the temperature of the concrete (½ in. below the top surface) to 35 deg F. This procedure kept further hydration to a minimum during the course of the test.

The amount of water frozen on the slab was 250 ml. The freezing was accomplished in a room maintained at -20 deg F. Thawing took place in a room at approximately 73 deg F. Upon removal from the cold room, commercial flake calcium chloride was used as the de-icer in the amount of 2.4 lb per sq yd of surface area, the maximum amount applied in practice. At the end of the thaw period, the solution was flushed off the surface and was replaced by 250 ml of fresh water for the freeze portion of the cycle. The slabs were in the freezer room for approximately 20 hours and in the thaw room approximately 4 hours.

At intervals during the scaling test, the surfaces were examined, rated as to extent and depth of scale and assigned a numerical rating as follows:

0 - no scaling	3 - moderate scaling
1 - very slight scaling	4 - moderate to bad scaling
2 - slight to moderate scaling	5 - severe scaling

In addition to the visual ratings, photographs of the surfaces were taken periodically to provide a record of the amount and rate of development of scaling.

DISCUSSION OF RESULTS

This series of laboratory tests was conducted in order to secure information which would be of value in determining the minimum amount of curing required before permitting the use of de-icers on air-entrained concrete pavements. Non-air-entrained concretes were included for an over-all comparison with the air-entrained concretes.

In reviewing the results of these tests, two factors are believed to be of considerable significance. These are the continuous moist curing of the concretes prior to test and

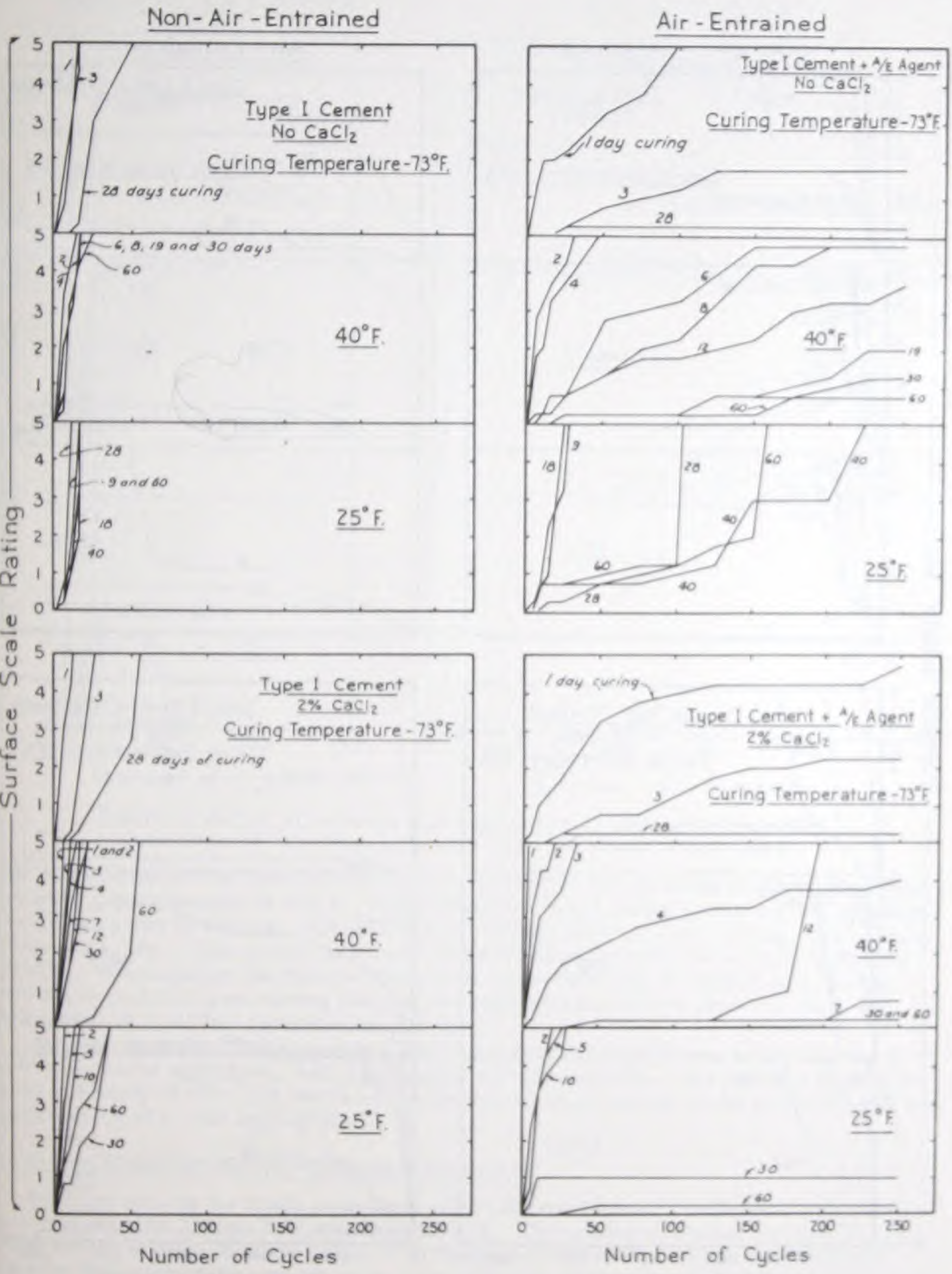

Figure 1. Effect of duration and temperature of curing on the scale resistance on concretes made with Type I cement - Lot 18868.

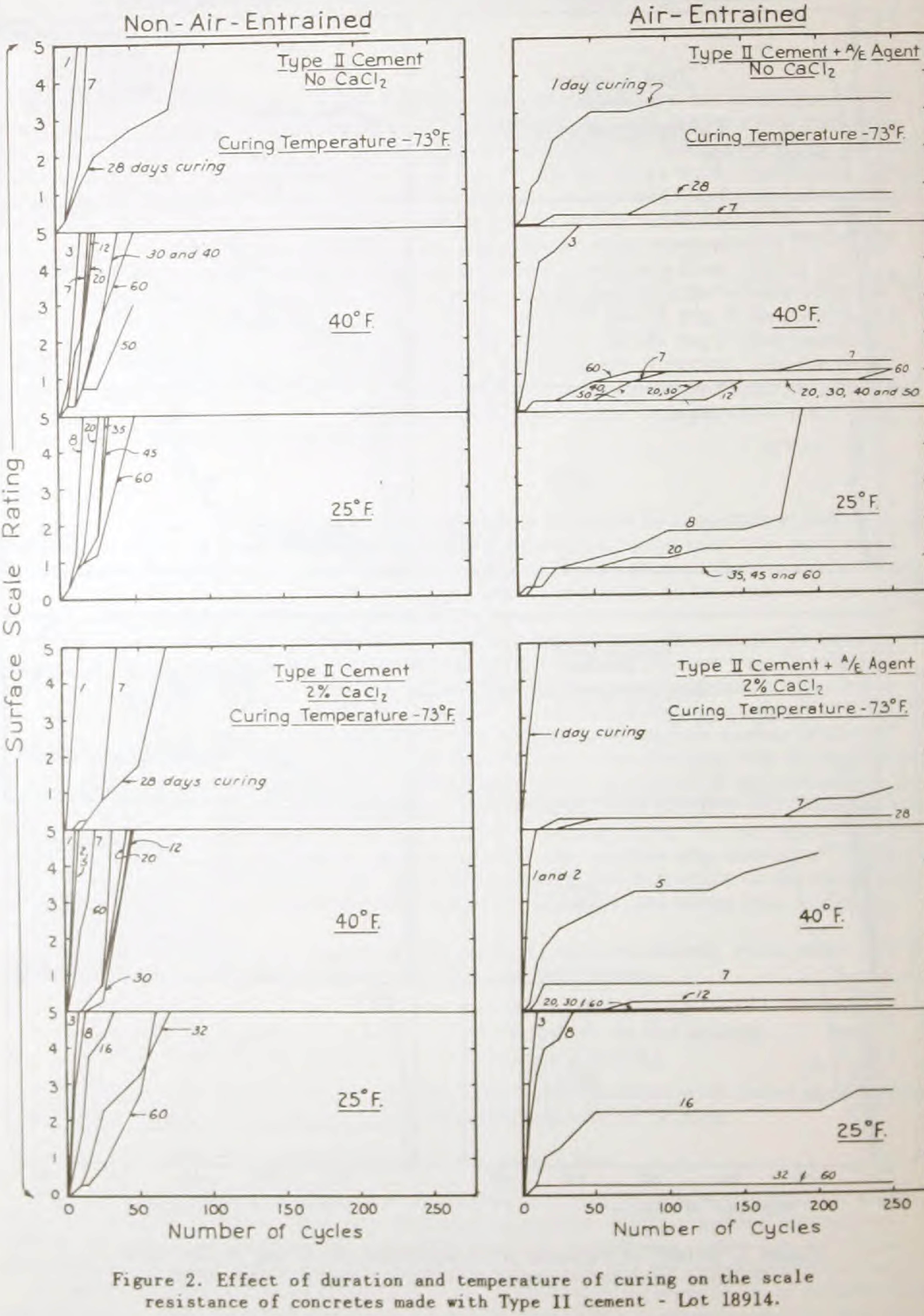

Figure 2. Effect of duration and temperature of curing on the scale resistance of concretes made with Type II cement - Lot 18914.

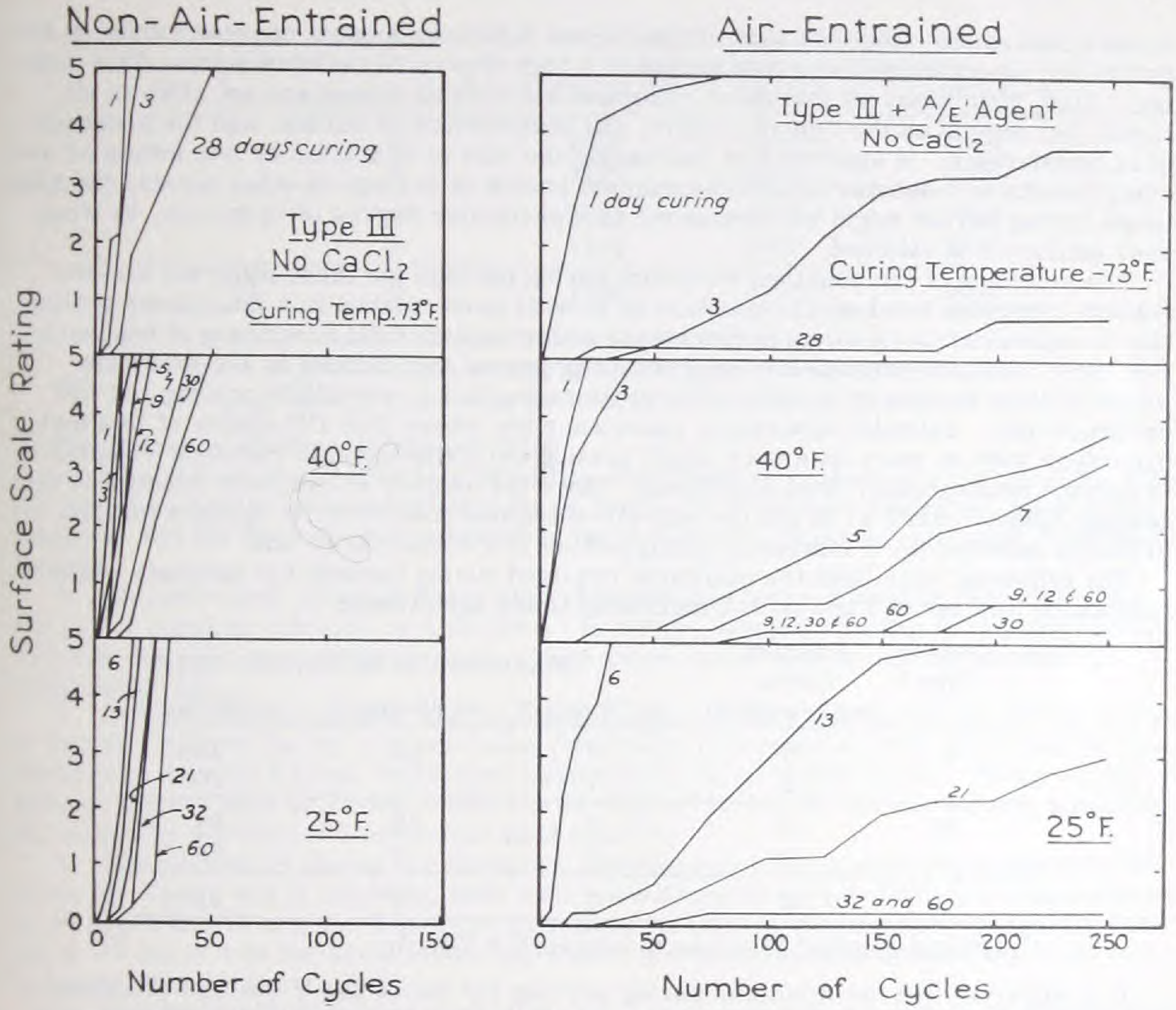

Figure 3. Effect of duration and temperature of curing on the scale resistance of concretes made with Type III cement - Lot 18893.

the termination of the thaw portion of each cycle when the concrete surface temperature reached approximately 35 deg F. The continuous moist curing prevented drying of the concretes prior to testing. All concrete pavements undergo some drying, even during their early life. This drying in almost all cases increases the resistance to surface scaling. Terminating the thaw portion of the cycle at 35 deg F tends to keep further hydration at a minimum during the test and represents a severe exposure from the standpoint of continued hydration or curing.

Another important factor is that these tests were made with one combination of a fine and coarse aggregate, both having good service records. The use of a poor aggregate in a study of this type would not be warranted since curing would not overcome the deficiencies of a poor aggregate.

Scale Resistance of Non-Air-Entrained Concretes

Detailed data on the scale resistance of the different non-air-entrained concretes are presented in Tables 7-11 and Figures 1-3. The number of cycles required to produce severe scaling (a scale rating of 5) ranged from 5 to 83. These data indicate clearly that none of the non-air-entrained concretes showed a satisfactory degree of resistance to surface scaling — regardless of temperature, amount of prior curing, type of cement, or the use of an accelerator.

Scale Resistance of Air-Entrained Concretes

Tables 7-11 and Figures 1-3 show the same detailed information for the air-en-

trained concretes. The data indicate that some minimum amount of prior curing is required for air-entrained concrete to insure a high degree of resistance to surface scaling. Also, it is apparent that these minimum amounts of curing are not alike in all cases, but depend on the type of cement, the temperature of curing, and the presence of an accelerator. It appears that increasing the rate of hydration by one means or another results in a shorter required minimum period of curing; in other words, the minimum curing period might be considered as a particular degree of hydration, by whatever manner it is attained.

The selection of the required minimum curing periods for these different air-entrained concretes involves the question as to what performance in a laboratory scaling test is equivalent to excellent performance under various field conditions of exposure. For these tests, the minimum required curing period was defined as the minimum length of time necessary to reduce the scale rating to 1 (very slight scaling) at 100 cycles of test. Extended laboratory experience has shown that 100 cycles of this test procedure with no more than very slight scaling normally indicate excellent resistance to surface scaling under field conditions. Since the number of cycles to produce severe scaling ranged from 5 to 83 for the non-air-entrained concretes, it appears that the criterion selected for a minimum curing period is a conservative one.

The following table lists the minimum required curing periods for adequate scale resistance (the use of Figures 1-3 facilitates these selections):

Cement Type [a]	Percent $CaCl_2$ (accelerator)	Minimum Curing Period - days at 73 deg F	at 40 deg F	at 25 deg F
I	0	7	15	60+
	2	7	7	30
II	0	7	12	35
	2	7	7	28
III	0	7	7	24

[a] A/E agent added at mixer to entrain 5 ± ½% air.

It is apparent that the minimum curing periods for the 25 deg F storage condition are long, and in some cases uncertain, emphasizing the importance of temperature of curing, as well as duration. For Types I and II, the use of an accelerator was beneficial at the lower curing temperatures, but was not beneficial at 73 deg F.

Considering the 73 deg F and 40 deg F temperatures, it is evident that the minimum curing periods for these air-entrained laboratory concretes are approximately the same as normally required by highway departments to insure adequate development of strength before opening to traffic. These laboratory tests indicate that air-entrained concretes cured at temperatures of 40 deg F or higher require no more curing to develop adequate scale resistance than to develop an adequate level of strength. These minimum curing periods might be increased somewhat in recommendations for field practice. In special cases, a factor of 3 seems justified to allow for additional influences on field concrete.

The strengths developed by these concretes at the minimum curing periods are shown in the table on the following page. At 73 deg F and 40 deg F the strengths range from 3250 to 4500 psi, the average being 3740 psi. It appears that the minimum curing period prior to permitting the use of de-icers was indicated by the development of a compressive strength level of about 4000 psi.

SUMMARY AND CONCLUSIONS

These laboratory tests have provided a basis for the determination of minimum required curing periods for concretes prior to permitting the use of calcium chloride as a de-icer. The moisture condition of the specimen and the manner of testing were such that the conclusions reached should be on the conservative side. This presumes the use of acceptable aggregates and the optimum air content for the concrete mix.

Cement Type[a]	Percent $CaCl_2$ (accelerator)	Compressive Strength - psi Minimum Curing Period at 73 deg F	at 40 deg F	at 25 deg F
I	0	3800	3900	(1010)[b]
	2	4100	3700	2300
II	0	3250	3400	880
	2	4500	3300	3200
III	0	3700	3750	3050

[a] A/E agent added at mixer to entrain 5 ± ½% air.
[b] Figure in parentheses is strength developed at maximum period of curing. These concretes showed poor resistance to scaling.

The following statements appear valid:

1. Non-air-entrained concrete has little resistance to surface scaling resulting from the use of de-icers. Increased amounts of curing up to 60 days raised the level of resistance, but the highest level attained by these non-air-entrained concretes is unsatisfactory.
2. Air-entrained concrete has a high resistance to surface scaling resulting from the use of calcium chloride as a de-icer. However, adequate curing is required before calcium chloride may safely be used. This should apply also to the use of other deicing materials.
3. At temperatures above freezing (specifically at 40 deg F and 73 deg F) the amount of curing required for the air-entrained laboratory concretes is little more than is necessary to develop a level of strength sufficient to carry traffic loads. These curing periods were 7 days at 73 deg F and 7 to 15 days at 40 deg F. These periods should be increased by a factor of 3 for actual field practice.
4. The periods of curing for these air-entrained concretes were approximately the same for Type I and II cements, both with and without an accelerator, for temperatures of 40 deg F and 73 deg F. For Type III cement without an accelerator, the curing period at 73 deg F was the same as for the Type I and II cements, but at 40 deg F the required curing period was less.
5. For these air-entrained concretes, the use of calcium chloride as an accelerator resulted in shorter minimum curing periods at temperatures of 40 deg F and 25 deg F.
6. A curing temperature below freezing (25 deg F) resulted in excessively long curing periods. In some cases where adequate scale resistance was obtained, the concrete is unacceptable because of low strength.
7. The development of a certain level of strength has merit as an index to the amount of curing required for air-entrained concrete prior to permitting the use of deicers.

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HRB:OR-63